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14. ABSTRACT

In order to estimate energy expended and metabolic heat produced during Border Patrol (BP) training or operations, 14 male BP personnel were studied over the course of a day. Energy expenditures in kilocalories (kcal) was determined for each activity by individual. Total energy expenditure for the work day (-7 hours) was then established and metabolic heat production estimated assuming mechanical 20% for human movement. It was found that BP personnel expended approximately 1750 +/- 540 kcal during their work day which would result in an estimated 24-hour daily energy expenditure of 3150 kcal. An average of 240 +/- 60 W of heat was produced over the entire work day (1 kcal/hr = 1.163 W). Peak metabolic heat production for activities lasting 30 minutes or longer was an estimated 360 +/- 204 W.

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METABOLIC HEAT AND ENERGY EXPEDITURE ESTIMATES OF BORDER PATROL PERSONNEL

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EXECUTIVE SUMMARY

Border Patrol personnel working the southern United States border face harsh working conditions, especially during Summer months when temperatures routinely exceed 37.8°C (100°F). These individuals may spend up to 72 continuous hours working in extreme temperatures. The resulting thermal strain (i.e., elevated skin and core temperatures) can be a serious issue with an increased potential for heat illness and injury. The level of thermal strain imposed upon Border Patrol personnel is currently unknown. However, anecdotal evidence suggests that missions and/or the health of Border Patrol personnel may be compromised. Thermal strain is affected by mission requirements, environmental conditions, clothing and equipment worn, and various individual characteristics such as whether a person is heat acclimated, their health status, percent body fat, and physical fitness. With regard to mission requirements, the metabolic heat produced varies based on levels of physical activity. Metabolic heat production is related to the physical activity energy expenditure of an individual. **Study Goal:** The purpose of this study was to estimate energy expended and metabolic heat produced during Border Patrol training or operations. Metabolic heat production is a key input to predictive thermoregulatory models. Using this information along with environmental conditions, individual characteristics, etc., these models estimate core temperature trends over time which can then be used for mission planning purposes (e.g., work/rest cycles) or to estimate the cooling requirements needed to provide sufficient cooling for Border Patrol personnel. **Methods:** Fourteen male Border Patrol personnel (age: 34.5 $\pm$ 4.3 yrs, wt: 81.8 $\pm$ 8.6 kg, ht: 175 $\pm$ 8 cm) were studied over the course of a day. Global positioning systems (GPSs) were worn for the entire assessment day to obtain rates of movement and distance travelled. These measurements plus body weight and load carried allow for prediction of energy expenditures when the primary activity is locomotion on foot. Standardized energy expenditure prediction equations were used. Energy expenditure for all activities, including locomotion activities, was also estimated using the factorial method. When GPS data was available the energy cost of foot movements estimated using the standardized prediction equations were used instead of the factorial method prediction estimates. Activity type and the length of time of each activity were obtained from focus group interviews. Energy expenditures in kilocalories (kcal) were determined for each activity by individual. Total energy expenditure for the work day (~ 7 hours) was then established and metabolic heat production estimated assuming mechanical efficiency of 20% for human movement. **Results:** Border Patrol personnel expended approximately 1750 $\pm$ 540 kcal during their work day which would result in an estimated 24-hour daily energy expenditure of 3150 kcal. An average of 240 $\pm$ 60 W of heat was produced over the entire work day (1 kcal/hr = 1.163 W). Peak metabolic heat production for activities lasting 30 minutes or longer was an estimated 360 $\pm$ 204 W. Individual plots showed large variability in the amount and pattern of metabolic heat produced. **Conclusions:** The average metabolic heat produced over the work day was low (~240 W). While there were bursts of high activity, most Border Patrol personnel spent large parts of their day either standing or sitting. Nevertheless, high levels (> 500 W) of metabolic heat can be produced during peak periods of activity. During periods of peak heat production in

hot environmental conditions, high levels of thermal strain could ensue, leading to an increase risk in heat illnesses and injuries.

INTRODUCTION

Harsh environmental conditions exist for the Border Patrol Tactical Unit (BORTAC) and Border Patrol Search, Trauma, and Rescue (BORSTAR) agents conducting their missions along the southern U.S. border. Key locations of border control along the southern border include Del Rio and El Paso, Texas, Tucson and Yuma, Arizona and Calexio and San Ysidro (near San Diego), California. Temperatures vary among these locales but according to the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service database (http://www.nws.noaa.gov; accessed 26 July 2010) and the Western Regional Climate Center (http://www.wrcc.dri.edu; accessed 26 July 2010) websites, temperatures can routinely exceed 37.8°C (100°F). For example, in Del Rio, Texas, the location of Border Patrol activities observed in this study, the hottest day on record was 44.4°C (112°F). During the summer, daily highs exceed 32.2°C (90°F) on 80% of days. Since 1879 in El Paso, Texas there has never been a year when temperatures during the summer months did not exceed 37.8°C. On average there are 15 days each year when temperatures surpass this mark. The record high temperature for El Paso, Texas is 45.6°C (114°F). In Yuma, Arizona average high temperatures for the summer months have exceeded 37.8°C every year since 1930 with an average of 173 days a year of temperatures above 32.2°C. Both Yuma and Tucson, Arizona have a record high temperature of 47.2°C (117°F). Tucson, Arizona routinely has average temperatures exceeding 37.8°C for the month of June. Temperatures near San Diego, California tend to be milder due to the cooling effects of the Pacific Ocean.

Little information is available on the effects the environment and Border Patrol mission requirements have on the thermal strain experienced by these agents. However, there have been a number of studies documenting thermal injuries and related deaths of undocumented immigrants that Border Patrol agents are attempting to apprehend (9, 13). While some of the conditions are unique to the immigrants themselves; such as lack of water, being smuggled in cramped vehicle spaces, and exercising beyond the recommended work-rest cycles to avoid being caught by authorities; the hot desert environment is present for both the immigrants and Border Patrol agents alike. Deluca et al. (9) reported over 100 immigrant heat injury deaths a year in the Tucson, Arizona area alone.

In addition to high ambient temperatures, factors important in determining the thermal strain experienced by Border Patrol personnel include individual characteristics, the clothing and equipment worn, mission requirements and metabolic rates (10, 19). Knowledge of these factors allows the prediction of thermal work strain, water requirements, and nutritional requirements (10). While capturing weather information, clothing and equipment, and personal characteristics of a particular group of interest is relatively straightforward, obtaining an estimate of metabolic rate and metabolic heat production can be more challenging. Metabolic rate and metabolic heat production can be assessed through indirect or direct calorimetry, neither of which is practical for field measurements with Border Patrol agents while engaged in actual missions or occupational training because they require special laboratories or outfitting the individual with body-worn devices to capture and/or analyze their expired air (16). Use of doubly labeled water, while accurate and relatively non-invasive is expensive and provides total daily energy expenditure rather than minute-to-minute or hourly values for energy expenditure (16). An approach that does allow changes in metabolic rate to be non-invasively assessed in relatively small time increments is the factorial or diary method whereby an individual or data collector records the activities as they occur (16). These activities are then compared to previously obtained metabolic rates (2, 3) to determine energy expenditures and metabolic heat production using standardized equations (16). A variant of this factorial method was used in this study. Focus groups of Border Patrol agents were assembled; during these groups agents verbally recreated the activities of their day. Having individuals that performed the same activities or were in the same vicinity during their work day as others in their focus group allowed the various activities they described to be confirmed or corrected by other focus group members. This likely increased the accuracy of these post hoc self-reported activities. The specifics of the methods used during this study are described below.

The research objective was to obtain an estimate of rates of energy expenditure and metabolic heat production. This information could then be used as inputs into models to estimate the thermal strain agents would likely experience for a given set of environmental conditions. From these estimates, strategies for mitigating this thermal strain can be developed. These strategies may include mission planning changes and/or materiel solutions. One materiel solution being considered is the use of microclimate cooling systems. Examples of microclimate cooling systems are vests filled with cooled air or fluid worn next to the body to reduce the body's temperature. Knowing metabolic rates and the duration an agent performs work at an elevated rate will help developers define the level of cooling necessary to keep the increase in thermal strain to a safe level. Cooling systems have power requirements and the more powerful the system, the heavier it is likely to be. Agents are unlikely to wear something that is heavy and bulky. Therefore, the goal is to develop cooling systems that are as light and small as possible but at the same time provides enough cooling to meet the heat dissipation requirements of these agents. The information gathered during this study, and the information provided by thermoregulatory modeling will provide developers with the information they need to produce lightweight and effective cooling systems that reduce the thermal strain imposed on Border Patrol agents.

METHODS

A modified factorial method was used to estimate energy expenditures (16) along with data from Global Positioning Systems (GPS) worn by agents. Briefly, a list of activities and time spent during each activity was recorded from each volunteer from information they provided during a structured focus group as opposed to the classic factorial method in which direct observation is used. Volunteers were also questioned on their trait characteristics during the focus group. Detailed methodology regarding the conduct of the focus groups is described below.

VOLUNTEERS

Fourteen male Border Patrol agents recruited from the Del Rio, Texas Special Operations unit volunteered for this study. There were nine BORTAC and five BORSTAR volunteers. Of these 14 volunteers, four were canine handlers, two were sniper/precision marksmanship observers, and the other eight were regular Special Operation agents. Three individuals had supervisory responsibilities. Volunteers were briefed on the purpose, risks, and benefits of the study and gave their written informed consent prior to study participation. This study was approved by the Scientific and Human Use Review Committees at the U.S. Army Research Institute of Environmental Medicine.

Border Patrol agents averaged 34.5 ± 4.3 (S.D.) years of age and had 8.6 ± 3.4 years of Border Patrol experience with 4.5 ± 3.8 years of experience at the Del Rio, Texas duty station. Volunteers weighed 81.8 ± 8.6 kg and were 175 ± 8 cm tall. These agents typically engaged in regular physical training, briefings, etc. on a daily basis. All agents had trucks assigned to them for the purpose of completing their missions. All gear worn during training or actual missions was stored in their trucks. They all had recent experience (within the last 60 days) on an actual mission, defined as a particular mission of rescuing someone, tracking illegal aliens, or responding to a location of known criminal activity and engaging these suspected criminals. The majority (10 of 14) reported that their last actual mission took place in Eagle Springs, Texas. Routine patrolling, responding to calls that did not result in the above activities was not considered being engaged in an actual mission. The last training mission was within the last 45 days for all volunteers.

Six individuals used tobacco products. Of these six individuals all used smokeless tobacco, while one used smokeless tobacco, cigarettes, and cigars. Volunteers had run either a 2-mile run (14:06 ± 1:48) (n = 5) or a 1.5-mile run (10:27 ± 0:42) (n = 9) for time within the last 45 days. Average per mile pace was similar regardless of the distance run (7:03 min/mile for 2-mile run vs. 6:58 min/mile pace for 1.5-mile run). During physical training these individuals reported averaging 6.4 ± 1.7 miles of running per workout, min = 3 miles, max = 8 miles.

EXPERIMENTAL PROCEDURE

Volunteers wore a Garmin ForeTrex 101 GPS (Garmin, Olathe, KS) on their wrist for the entire in-the-field work day. One group conducted an actual mission by responding to a potential threat with search-type activities for illegal immigrants or individuals engaged in illegal activities but this mission did not result in the Border Patrol coming in contact with any such individuals. Two groups of volunteers participated in training activities. The first training activity was similar to the actual mission of the group searching for illegal aliens or individuals conducting illegal activities in a high risk area. The other training session involved BORSTAR agents simulating a search and rescue operation using Border Patrol service dogs. An agent served as a lost person or illegal immigrant trying to evade authorities. This agent laid a trail, while another agent and his dog tracked the trail of the first agent approximately 20 minutes later.

The following day volunteers filled out a brief background questionnaire. All information was obtained without the use of names, that is, only an assigned volunteer identification number was used. Data was gathered anonymously to enhance candor. Questions included demographic questions (e.g., age, height, and weight) and job experience questions (e.g., time served in the Border Patrol, job position, and rank). Volunteers then participated in focus groups to reconstruct the various activities of the previous work day. Three focus group sessions, with two groups of five and one group of six individuals, were held. These sessions were video-taped. The use of focus groups allowed individuals to describe the previous day's activities in detail, including time spent doing each activity and what they were wearing or carrying. The moderator followed recommended guidelines for focus groups such as not using jargon, making sure all volunteers contributed their ideas and/or experiences, did not allow one participant to dominate the conversation, and validated each idea as important (1). Topics besides the re-constructing of a day's activities proceeded from general to more specific as has been recommended (15). The videos from the focus group sessions were transcribed to a written narrative. From these narratives, data files were constructed in Microsoft Excel (Microsoft Corporation, Redmond, WA) that included activity, time engaged in each activity, body weight, weight carried, and environment the activity took place in (e.g., sitting in a car, walking on rocky trails, etc.).

During the focus group sessions volunteers were asked to provide a subjective rating of the maximum level of heat stress they experienced during the previous day's activities. The heat stress scale was presented verbally on a one to ten scale. A "1" was defined as no heat stress such as being in an air conditioned office and a "10" was defined as the heat stress imposed that would push a person to the point of heat exhaustion where they felt they might pass out. Other questions asked included what were the most strenuous missions they had participated in, number and nature of previous heat injuries, issues associated with proper fluid requirements, amount of and frequency of tobacco use, and amount of sleep obtained the night before the previous day's activities.

CALCULATIONS

For each activity a MET level was assigned by taking that activity and matching it to the closest activity in Ainsworth et al.'s (2, 3) compendia of physical activities. Activities in the compendia are expressed in terms of MET levels of energy expenditure. A MET is defined as the ratio of metabolic work rate to a standard resting metabolic rate (16). Therefore, 1 MET = 1.0 kcal x body weight in kg per hour. For example, for an 80 kg person, sitting in a chair for an hour expending 1 MET, would equate to them expending 80 kcal for that hour. To calculate metabolic heat production, a mechanical efficiency of muscular work of 20% was assumed (19, 20). Therefore, total kcal expended was multiplied by 0.8 to represent that 80% of the kcal were expended as heat, while 20% of the kcal were expended in useful mechanical work. Locomotion activities (walking or running) that had available GPS data, used that data along with other variables (e.g., body weight and terrain characteristics etc.) to calculate energy expenditures using equations developed by Givoni and Goldman (11), Pandolf et al. (17), and Santee et al. (18). Energy expenditure values are presented in kilocalories (kcal). Metabolic heat production was converted to watts (W) of heat produced. The standard conversion equation of 1 kcal/hr equals 1.163 W was used.

DATA ANALYSIS

Data are presented as average watts of heat produced over the course of the work day, peak watts of heat produced for 15 and 30 minutes, and absolute peak watts of heat produced regardless of the length of time of a particular activity. Descriptive statistics are presented as means $\pm$ standard deviations (S.D.) and minimums (Min) and maximums (Max). All data except for energy expenditure and watts produced derived from GPS data are self-reported.

RESULTS

Estimated work day (~ 7 hours) active energy expenditure was 1750 $\pm$ 530 kcal. A rough estimate of total daily energy expenditure would be about 3150 kcal by adding active energy expenditure to a resting energy expenditure of approximately 1400 kcal. This resting energy expenditure value was calculated as resting energy expenditure (1 MET) multiplied by body weight and number of hours of non-active energy expenditure (16). These daily energy expenditure estimates would be slightly more than the 3150 kcal estimate if a person participated in vigorous activity outside of work or slightly less if they spent more than 6 hours sleeping (0.9 MET). Volunteers reported sleeping 5.2 $\pm$ 1.1 hours prior to the assessment day. The work day during this study was 6.8 $\pm$ 0.7 hours, which is shorter than normal because office activities took place prior to our briefing, including enrolling the volunteers into the study and administering the GPS devices.

Metabolic heat production unlike energy expenditure cannot be summed because watts are associated with time. Therefore, a specific time period of interest needs to be established. Within Table 1 are four time periods: [1] average for the whole work day, [2] peak activity, [3] peak activity lasting at least 15 minutes, and [4] peak activity lasting at least 30 minutes where metabolic heat production was calculated.

Table 1. Average rate of metabolic heat production during the work day, and peak rates of metabolic heat production (acute, ≥ 15 min or ≥ 30 min).

	Work Day Average			Peak			Peak ≥ 15 Minutes			Peak ≥ 30 Minutes		
	± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max
Heat Produced (W)	243 ± 59	180	361	823 ± 272	446	1451	522 ± 180	174	825	360 ± 204	130	701
Total Time (h:min)	6:48 ± 0:42	5:20	8:00	0:25 ± 0:18	0:01	1:44	0:42 ± 0:31	0:15	1:44	0:42 ± 0:31	0:30	1:44

The difference between “Peak ≥15 Minutes” or “Peak ≥ 30 Minutes” and “Peak” is that “Peak” could be a burst of activity that created a high watt level that only lasted for a couple of minutes, whereas “Peak ≥ 15 or ≥ 30 Minutes” was the highest level of activity sustained during the day that lasted for at least 15 or 30 minutes respectively. In some cases, it was the same amount of time and heat produced for a specific activity as “Peak.” A comparison of the peak watt output of at least 30 minutes or longer was less than that of the peak output of activities of at least 15 minutes or longer (30 minute peak: 360 ± 204 W vs. 15 minute peak: 522 ± 180 W).

Border Patrol personnel averaged 1.7 ± 0.9 bouts of exercise in excess of 30 minutes that lasted for an average of 0:53 ± 0:25 (h:min). Five agents had one bout, five agents had two bouts, and three agents had three bouts of exercise lasting 30 minutes or longer. One agent had no bouts of exercise lasting 30 minutes or longer. An exercise bout was considered any activity except for indoor activities, sitting in a vehicle, or sitting down outside. Standing or walking outside while wearing equipment was included along with more vigorous activities or exercises. Individual charts of the volunteers’ estimated metabolic heat outputs over time are provided as Appendix A. As may be observed from these charts there are large differences in the various activities over time for each individual. Additionally, there are large differences between individuals in the patterns of metabolic heat production.

When volunteers were asked to subjectively rate the maximum heat stress experienced during the previous day’s activities on a ten point scale (1 = No heat stress to 10 = Maximum heat stress you could experience before passing out) agents reported a mean rating of 4.8 ± 1.0, with the minimum rating a 3.5 and a maximum rating of 7.0. No one experienced any heat injuries during the assessment period. Four individuals did report that they had experienced a prior heat injury.

METABOLIC RATES (EXCLUDING ACTIVITIES INSIDE BUILDINGS OR VEHICLES)

Table 1 examined daily averages for Border Patrol personnel over the course of the whole day. The data presented in Table 2 excludes times when these volunteers were doing office work inside offices (mostly air conditioned) and within their vehicles which were either air conditioned or cooling was present because of air flow generated by driving with the windows down. By excluding these conditions, daily average heat produced due to Border Patrol activities increased from 243 ± 59 W to 314 ± 65 W. Time engaged in these Border Patrol activities, excluding indoor or vehicle activities, decreased from 6:48 ± 0:42 to 3:23 ± 1:11 (h:min).

Table 2. Average metabolic heat production and time of exercises associated with that heat production.

	Daily Average ± S.D.	Min	Max
Heat Produced (W)	314 ± 65	211	440
Time (h:min)	3:23 ± 1:11	1:22	5:18

COMPARISON OF METABOLIC RATES BY JOB TYPE

There were three job type classifications; agents, snipers, and canine handlers. No distinction between BORSTAR and BORTAC personnel was made because the various activities did not include any rescue operations during this study. Snipers did not participate in sniper activities; therefore they were classified as agents for these analyses. Table 3 shows the estimated metabolic heat production of these two groups, while Table 4 shows the peak metabolic heat production of activities lasting 30 minutes or longer. Activities inside offices or vehicles were excluded from data in Tables 3 and 4. No significant differences existed in daily average of heat produced or duration of the activities.

Table 3. Average metabolic heat production and time of exercises associated with that heat production by job type.

	Agents/Snipers (*n* = 10)			Canine Handlers (*n* = 4)		
	Daily Average ± S.D.	Min	Max	Daily Average ± S.D.	Min	Max
Heat Produced (W)	313 ± 73	211	440	318 ± 50	259	367
Time (h:min)	3:36 ± 1:12	2:04	5:18	2:54 ± 1:06	1:22	4:04

Table 4. Heat production of strenuous activities lasting 30 minutes or longer by job type.

	Agents/Snipers (*n* = 10)			Canine Handlers (*n* = 4)		
	Daily Average ± S.D.	Min	Max	Daily Average ± S.D.	Min	Max
Heat Produced (W)	391 ± 230	130	701	281 ± 98	167	398
Time (h:min)	0:56 ± 0:25	0:30	1:44	0:45 ± 0:30	0:30	1:30

MOST STRENUOUS ACTIVITIES REPORTED

Volunteers were asked how typical the activities were that they performed on the previous day. Most volunteers said most days were much more strenuous than the activities measured on the previous day within this study. Within the focus group session they were asked the question: "What is the most strenuous activity that you have done on this job in the last year?" to assess what might be the highest levels of metabolic heat produced. The agents reported that they may have carried as much as 45.5 kg (100 pounds) of gear during some activities. They also reported they may have had to be in the field for up to 72 continuous hours. The shortest working day reported was 9.2 $\pm$ 1.0 h with the longest working day averaging 59.6 $\pm$ 20.4 h. This longest working day consists of a multiple day mission with up to 72 hours of continuous field deployment. The activity reported by almost all agents of this sustained operation mission was the pursuit of illegal persons, over rough terrain. These pursuits included walking or slow running, sometimes with bursts of running or sprinting for short distances. The pursuit could cover up to 10 miles. Border Patrol agents typically carried approximately 13.6 kg (30 pounds) of gear during these pursuits. It was estimated that the pursuits last for between 4 and 10 hours with a mean of 4.9 $\pm$ 1.9 h.

OTHER COMMENTS

Some Border Patrol personnel reported they would not wear body armor or similar protective equipment because it increases the thermal load especially during the hot Summer months where temperatures routinely exceed 37.7°C. The second issue was specific to the canine handlers. Depending on the mission, it is possible that the working dogs could over-heat prior to their human handlers. Mission intensity or duration was sometimes reduced to ensure the safety of the dogs. Specific open-ended comments are listed in Table 5.

Border Patrol personnel are aware of the importance of hydration to prevent heat injury. All use on-the-move hydration systems during missions. During the assessment period personnel consumed 2.8 $\pm$ 1.1 liters of fluid. Often a portion of this fluid was in the form of soft drinks or sports drinks in addition to water consumed from the hydration systems.

Table 5. Open-ended comments made by Border Patrol personnel.

Response	*n*
In the summertime I will not wear the body armor.	3
I do not put on the bullet-proof vest because I would rather die from a bullet than from heat stroke.	1
The dog might get overheated first. The dog might be the limiting factor with regard to continuing with the mission as it will get overheated.	1
Depending on the time of year I might get exhausted before the dog because of the heat. In the summertime you waste energy, especially canine handlers. I want you to know it is not always the dog that gets overheated first.	1
In Texas we set some heat records right here where we work. With temperatures over 100 degrees Fahrenheit every day it is brutal on us.	1

DISCUSSION AND CONCLUSIONS

This study provided reasonable estimates of the metabolic heat produced during Border Patrol agents' training or actual mission activities. The energy expenditure of the agents, approximately 3150 kcal/day, is similar to military personnel that do not have extended work days (21). The Border Patrol agents' regular work day is relatively short compared to most previously studied military field training scenarios. Furthermore, the reported training from the previous day involved multiple hours spent riding in air conditioned cars with relatively low rates of energy expenditure. However, their day did involve sporadic bursts of high energy expenditure documented throughout the test day. They also reported extended operations (sometimes in excess of 24 hours), but it was not possible to estimate the energy expenditure associated with an extended operation level due to lack of data. When examining the metabolic heat production of these agents, it should be noted that the average heat production over the course of a day is rather low because of extended periods of time of sitting or standing with relatively little activity. However, during peak activities, metabolic heat production could be quite high, for example when a 90 kg agent runs uphill over rocky terrain, while carrying 13.6 kg (30 lb) or more. While bursts of activity of less than 10 minutes may not pose a significant problem with regard to thermal strain experienced by these agents, activities of 15 minutes to an hour in hot environmental conditions could pose a risk of heat illness or injury.

Currently, without cooling, Border Patrol personnel are susceptible to heat illnesses and injuries due to the thermal demands of the climate. Heat illnesses and injuries range from minor to life threatening. Minor heat injuries include sunburn, heat cramps, heat edema, and heat rashes (10). More serious problems include heat exhaustion, exertional heat injury, and heat stroke. Heat exhaustion does not result in any organ damage; the symptoms of heat exhaustion include weakness, fatigue, dizziness, nausea, headache, ataxia, muscle cramps, hyperventilation, hypotension and tachycardia (10). Victims of heat exhaustion recover rapidly when removed from the heat, cooled promptly and rehydrated. Exertional heat injury is more serious than heat exhaustion. Exertional heat injury results in mild organ or tissue injury and dysfunction, however, victims of exertional heat injuries do not display the neurological abnormalities associated with heat stroke injuries (6). Heat stroke is characterized by a core temperature greater than 40°C (104°F). Rising core body temperature can cause damage to multiple organs (4). It often results in central nervous system damage or dysfunction including delirium, convulsions, and coma (10). Exertional heat stroke is seen in active persons who are between the ages of 15 and 45 and often occurs in military personnel and athletes (14). Rapid cooling is necessary for survival from heat stroke.

In addition to thermal strain increasing the risk of heat illnesses or injuries, it decreases mental and physical performance. Tasks requiring attention to detail or concentration suffer significantly. Reaction and decision times are increased. Vigilance decreases somewhat after 30 minutes of heat stress but noticeably after two hours (10). With regard to physical performance, the cardiovascular system is strained by the need to divert blood flow to the skin to support heat dissipation compromising nutritional blood flow to the exercising muscles. Furthermore, a higher heart rate is necessary to maintain cardiac output as the blood pools in the skin and subcutaneous vascular beds (10).

Heat dissipation of Border Patrol personnel is compromised by the clothing and equipment they wear. On the one hand this heavy equipment, such as weapons and ammunition and body armor, reduces the risk of injury or death from altercations with suspected illegal aliens or suspected drug dealers or smugglers, but on the other hand increases the risk of thermal injuries because of the weight, encumbrance and insulation while working in hot environments. The equipment worn by agents inhibits air circulation, trapping moist warm air close to the body decreasing evaporative cooling. Sweat rates may reach up to two liters per hour (10), but the sweat must evaporate to allow for body cooling. To allow for evaporative cooling to take place, air circulation close to the skin must be maximized. Elevated core temperatures because evaporative cooling was compromised was documented in Marines on patrol in Iraq wearing properly secured body armor (7). When these Marines knew they were safe they opened up the front of their body armor increasing air flow next to the body, reducing core body temperatures. The body armor worn by Border Patrol agents was either a solid hard or soft protective vest that was put over the head (Figure 1) and could not be opened up to increase air flow. It would have to be completely removed. A change to body armor worn to a design that could be opened up in the center of the chest region as that shown in Figure 2, enhancing cooling, might increase the use of body armor.

Figure 1. Soft body armor worn by Border Patrol agents.

Figure 2. Military body armor with two panels secured with Velcro™ that can be opened in front.

(Photo: http://aviationweek.typepad.com/ares/for_grunts_only/ ; accessed 12 August 2010)

Fluids lost by sweating must be fully replaced or else dehydration will occur. Thirst is not a good indication of hydration as it lags several hours behind actual fluid need. Individuals performing moderate physical activity should consume 6-8 quarts of water a day and those engaged in extreme physical activity require 9-12 quarts of water in a temperate climate (10). During the workday that was observed, agents consumed only 2.8 $\pm$ 1.1 liters (approximately 3 quarts) of fluid throughout the day. Border Patrol personnel may or may not consume adequate fluids during actual missions based on their own knowledge, mission requirements, and proper attention to the consumption of fluids. Because of the remote desert environment obtaining drinking water in the field often is not an option. The only fluid likely to be consumed during a pursuit is what the agent is carrying. On-the-move hydration systems such as a Camelbak system (Camelbak Products LLC, Petaluma, CA) are used by most Border Patrol agents while on duty increasing the likelihood they are replacing lost fluids.

Other factors that can contribute to thermal injuries in these areas of Texas, Arizona, and California are the remoteness of the areas and the rugged terrain (9, 12, 13, 22) which can hamper quick rescue efforts. Furthermore, steep grades and uneven terrain increase energy expenditures and metabolic heat produced (17, 18). Border Patrol personnel and their rescue dogs often are required to locate lost persons in addition to apprehending suspected criminals in harsh and austere environmental conditions. Rescue efforts need to be sustained and done quickly to successfully find the person before they succumb to one or more of the hazards present in this environment, including ambient heat and lack of water. Because of the nature of these rescue efforts, possible thermal injuries to Border Patrol personnel and their dogs are real possibilities. The need to protect the Border Patrol dogs from heat injuries is also a prime consideration. Strategies for cooling military working dogs have been studied (5). The approach for cooling dogs in hot environments may be different than for humans because the dogs' evaporative cooling is done through panting as opposed to sweating through the skin (5). Microclimate cooling or methods of applying cool water to the coats of the dogs may still be strategies that can be pursued.

This study focused on heat production values obtained from agents from one Border Patrol location, the Del Rio, Texas location. Topographical differences in various locations such as the steeper grades that may have to be navigated in the El Paso, Texas area; or different missions, e.g., in El Paso, Texas or Tucson, Arizona may lead to different estimates of metabolic heat produced. From the current data it was observed that there was great variability between individuals and also within an individual over the course of his daily activities. When variability is high, a larger sample size is necessary to determine representative estimates of actual values (8). Therefore, the estimates provided within this report should only be used as initial estimates in assessing the metabolic heat production of Border Patrol agents. Caution should be used when generalizing these results to all Border Patrol missions. The classic factorial method has proven to be a valid method of assessing energy expenditures associated with various physical activities, however, this method usually is used with direct observation of the activities by data recorders or the participant filling out a diary as the activities occur. Future studies in addition to having a larger sample size from various locations should use actual physiological monitoring if possible to make these assessments to improve on the confidence of the values obtained. If physiological monitoring is not possible, direct observation by data collectors or other methods that may improve the confidence of the energy expenditure estimates should be considered.

The metabolic heat estimates and other factors cited above are useful for thermoregulatory model simulations. These models predict humans' core temperatures using inputs including environmental conditions, metabolic rates, and individuals' anthropometric and static traits. In turn, these estimates will allow cooling system developers to know how much cooling is needed to manage the thermal strain of these Border Patrol agents for the particular environmental and operational demands they encounter. Cooling units are necessary only to prevent heat injuries, not necessarily to ensure comfort. Agents wearing a vest may still feel warm, just not to the extent that they become a heat casualty. Adding un-necessary coolant will only add bulk and weight to the agents' load. Agents reported that they will not wear bulky or heavy protective vests and other equipment. In addition to developing products, such as cooling systems, proper mission planning to allow for work-rest cycles in accordance with approved guidance (10) and/or the use of physiological monitoring systems to allow an individual or his partner to know when he is getting close to a physiological danger zone could be used to reduce the threat of thermal injuries. Use of physiological monitoring systems could provide the information in real time to allow an individual or his partner to know when they must modify the mission for their own safety. Regardless of the strategy employed to reduce the risk of thermal injuries, this report provides initial documentation of the energy expenditures and metabolic heat production of Border Patrol agents to help guide those decisions.

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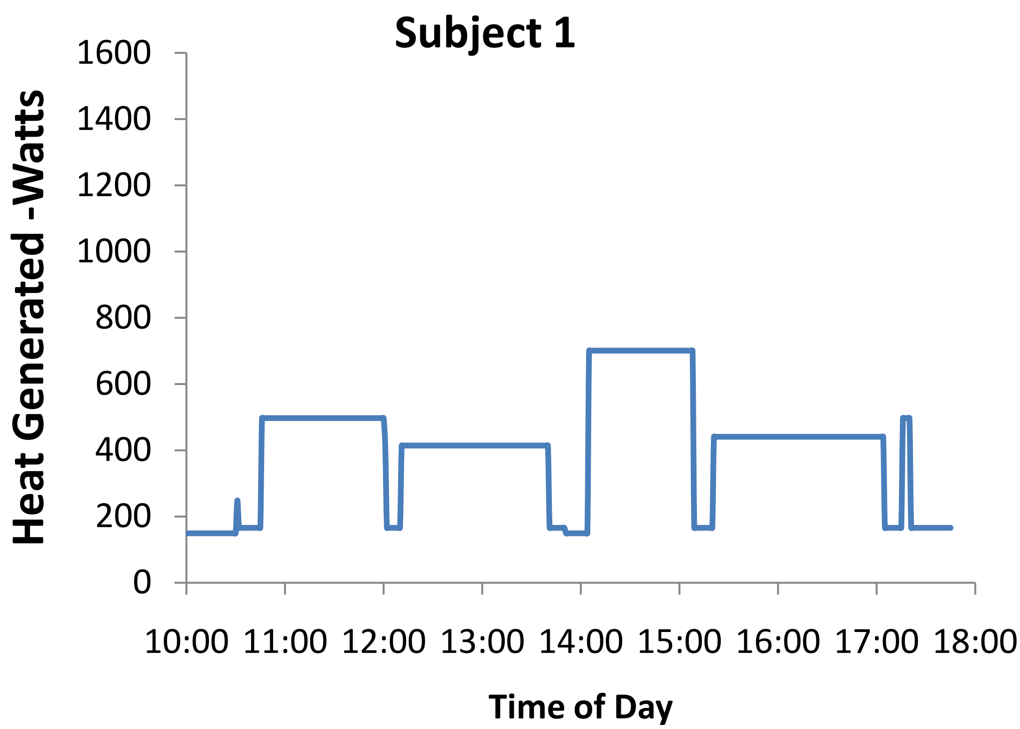
APPENDIX A

INDIVIDUAL SUBJECTS' METABOLIC HEAT GENERATED FROM WORK ACTIVITIES OVER THEIR ENTIRE WORK DAY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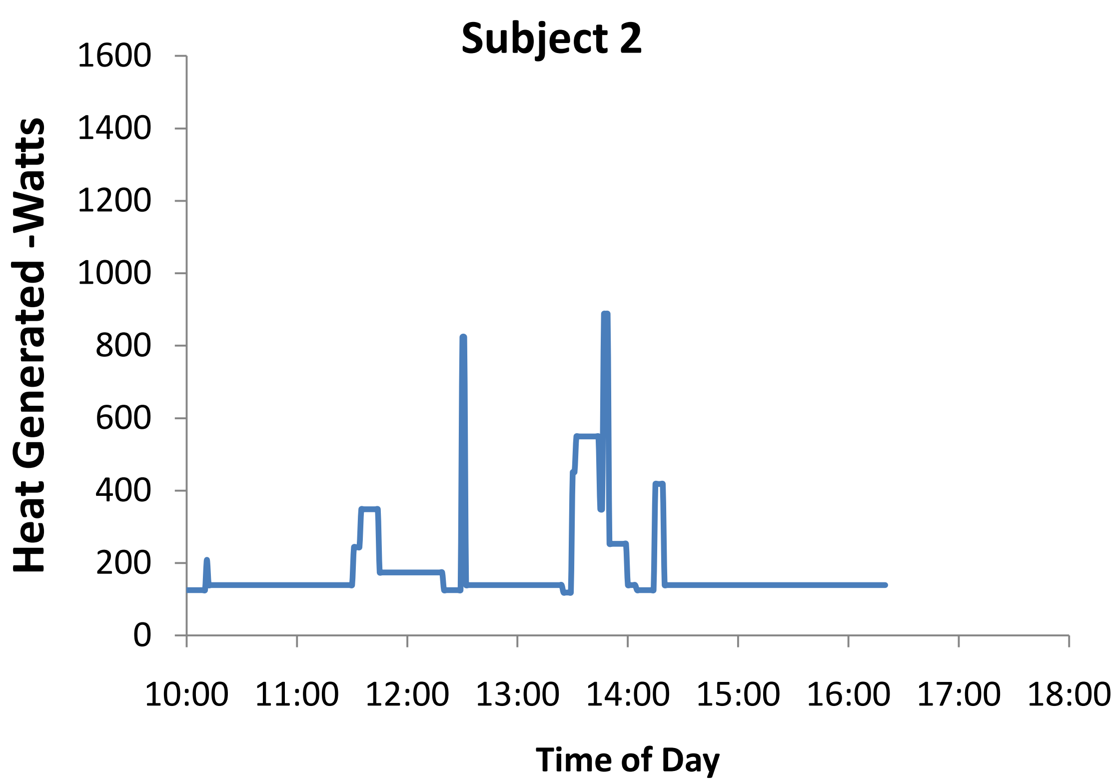
Time of Day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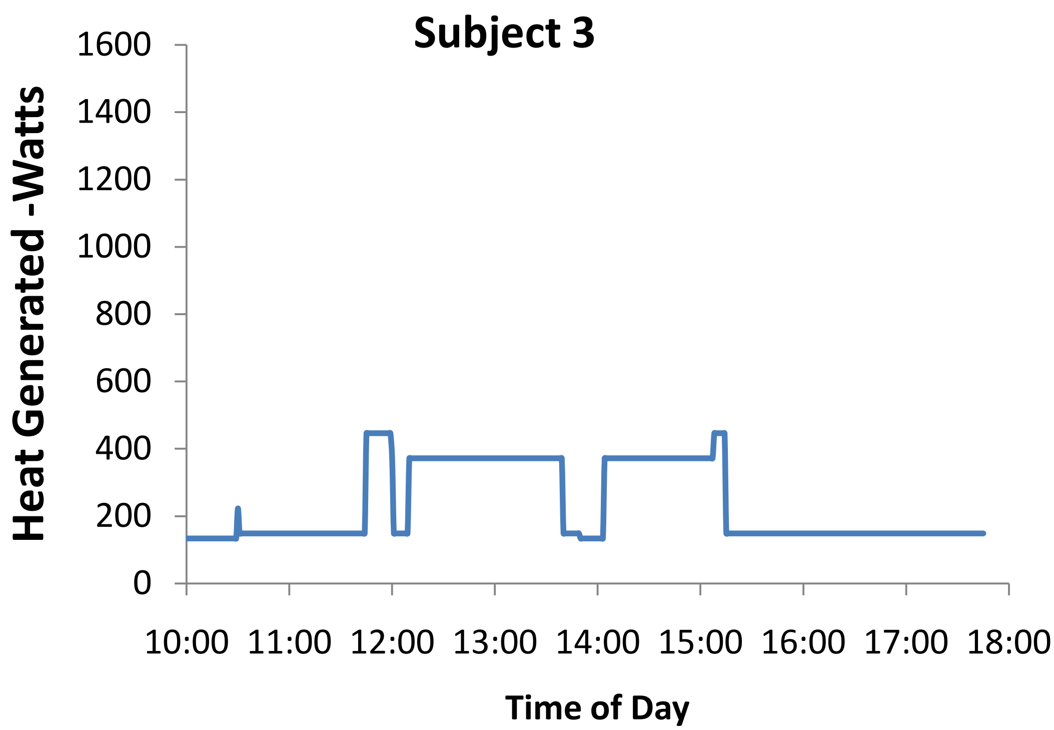
Time of Day



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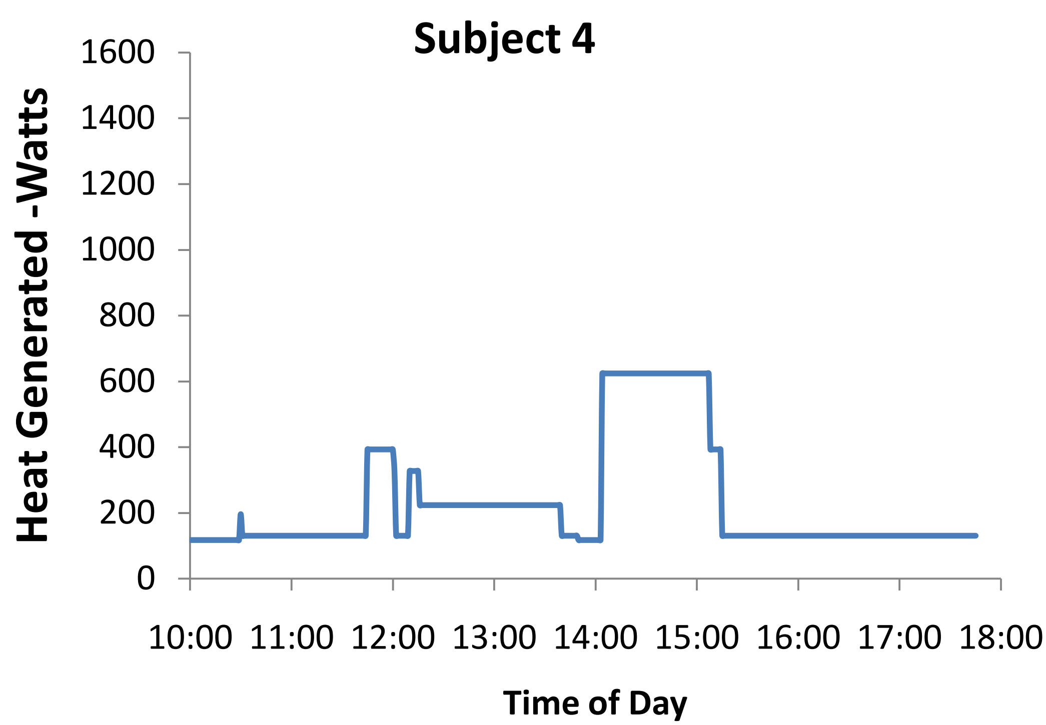
Time of Day



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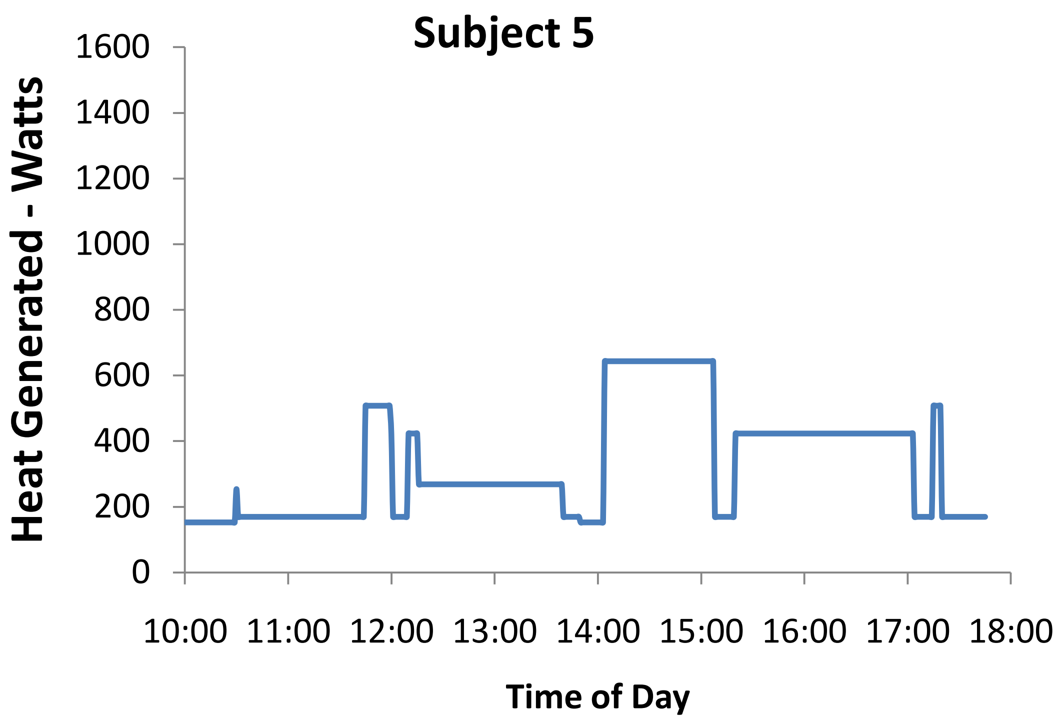
Time of Day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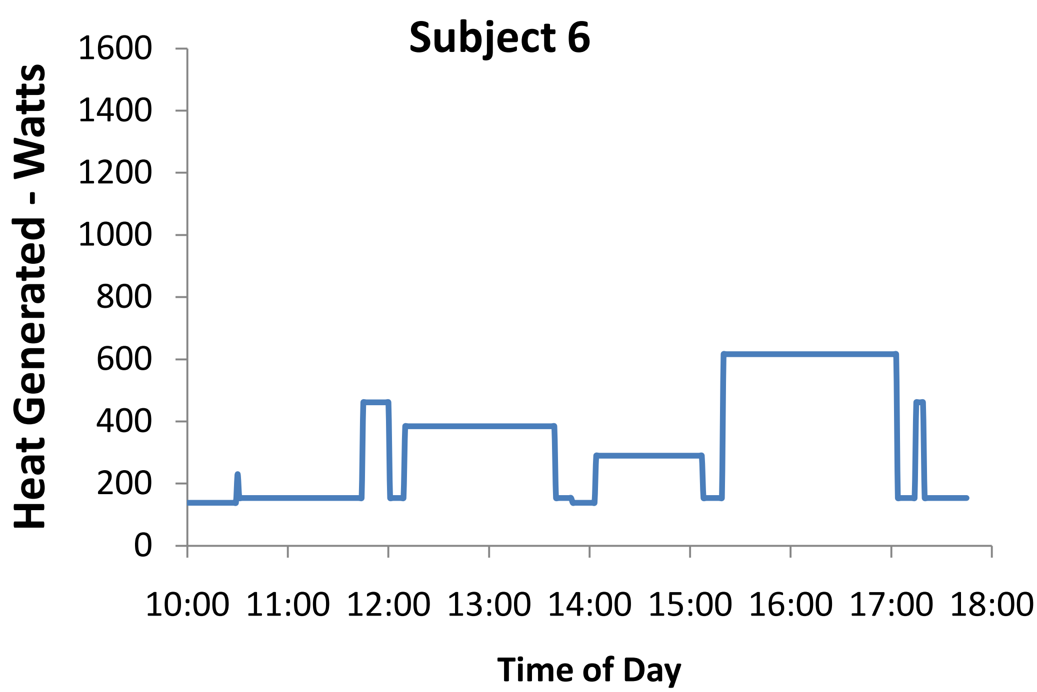
Time of Day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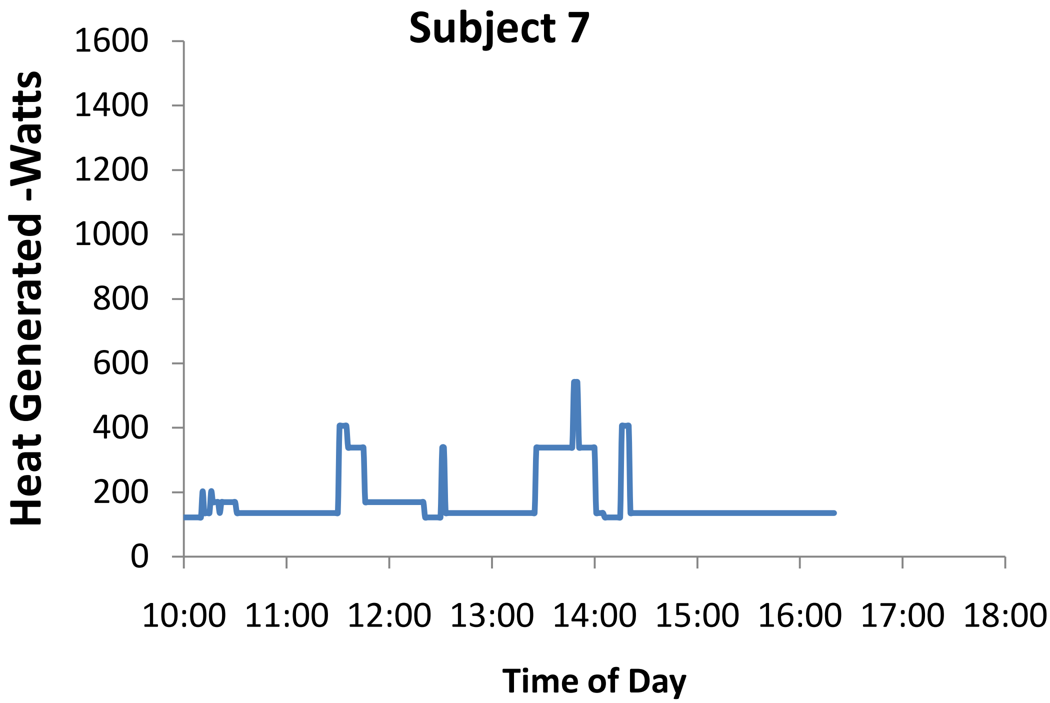
Time of Day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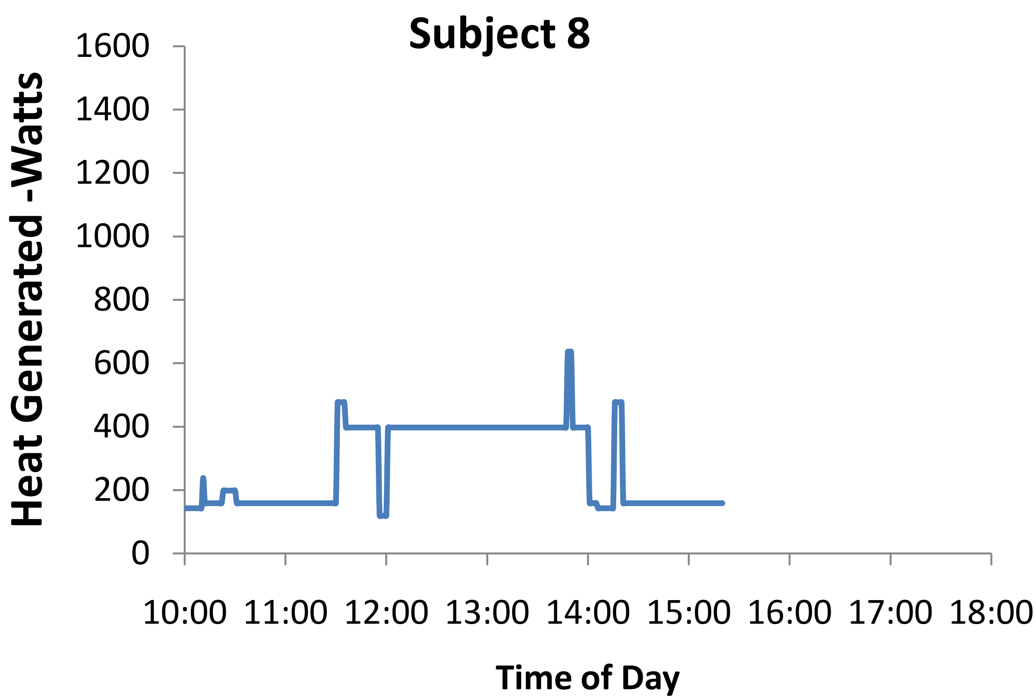
Time of Day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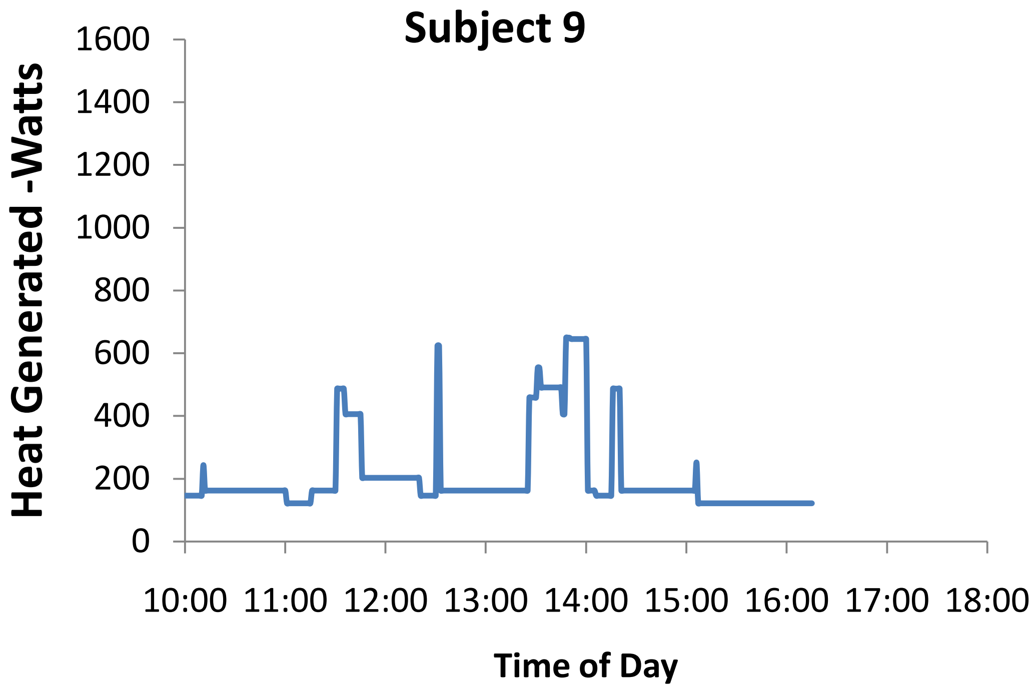
Time of Day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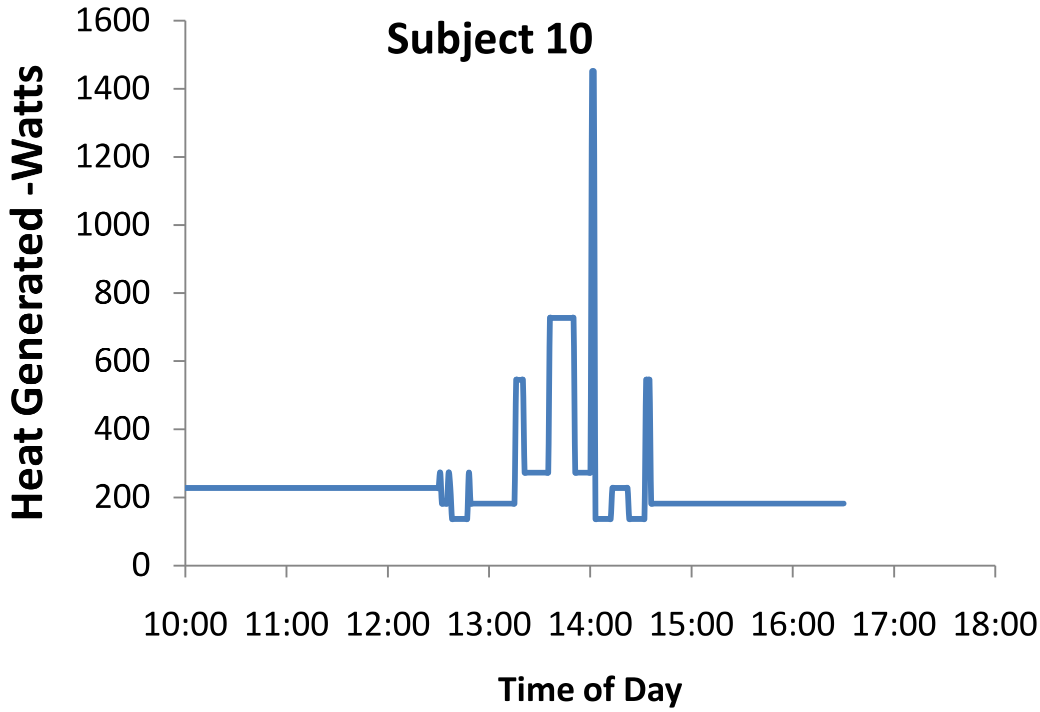
Time of Day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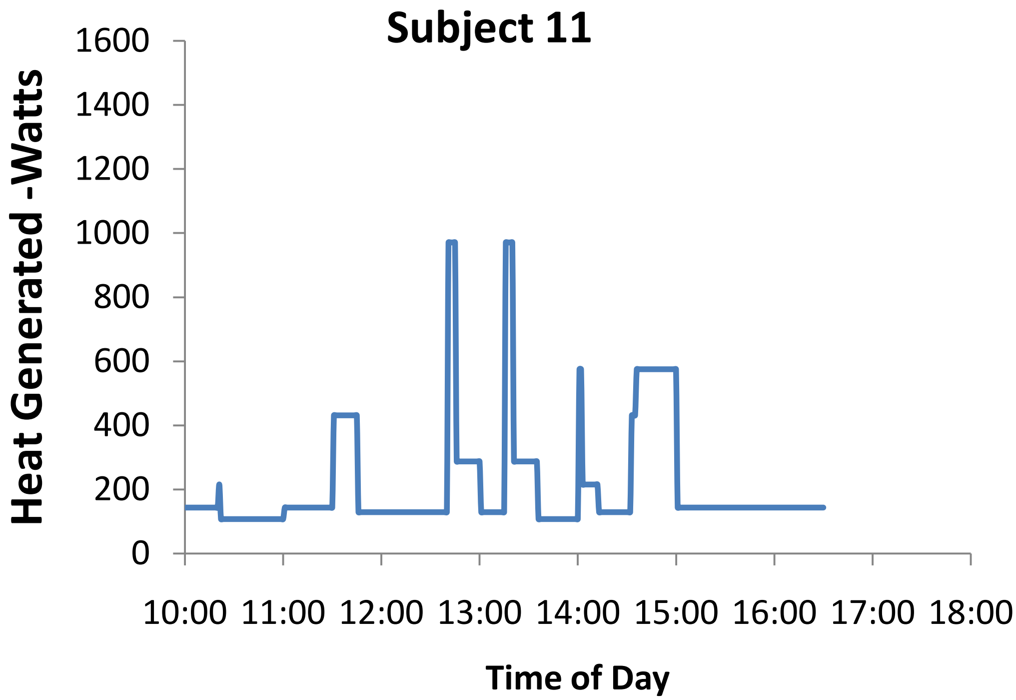
Time of Day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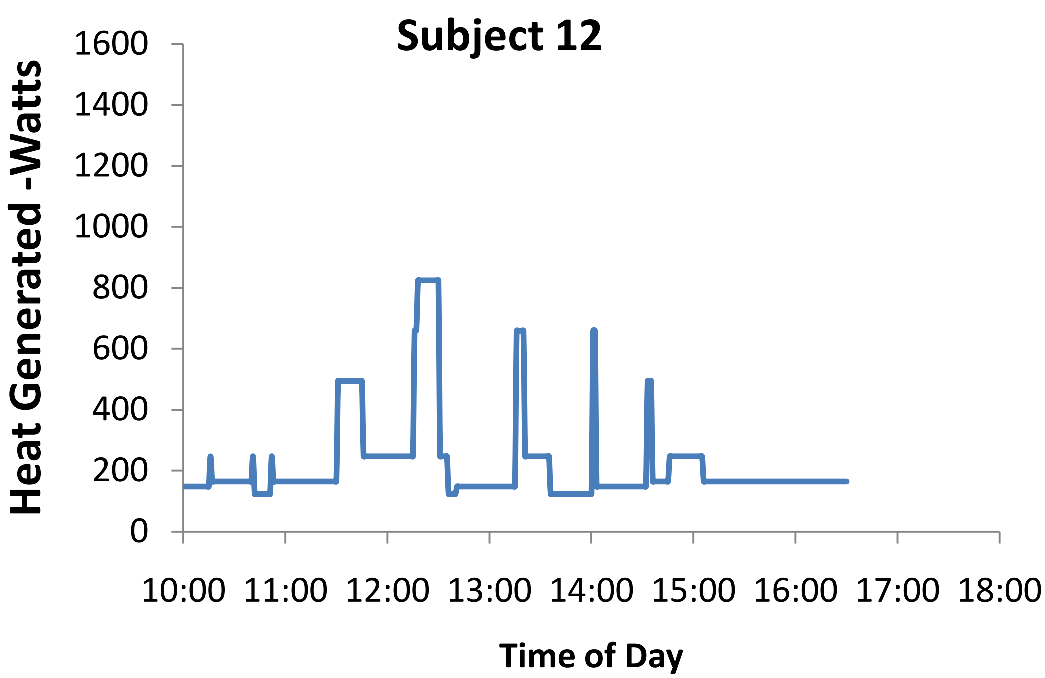
Time of Day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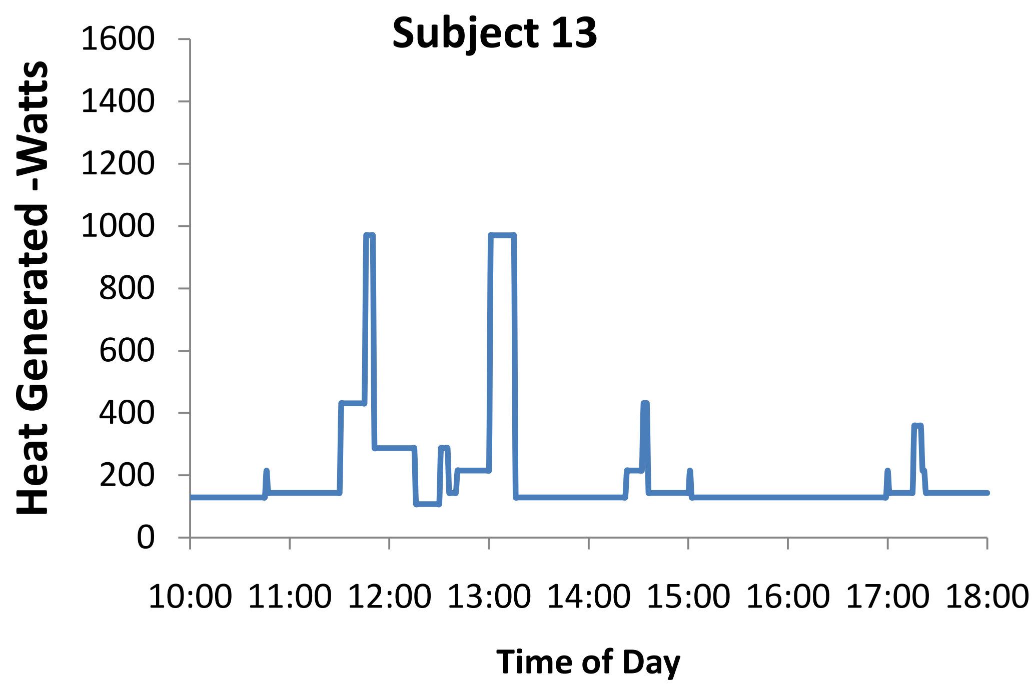
Time of Day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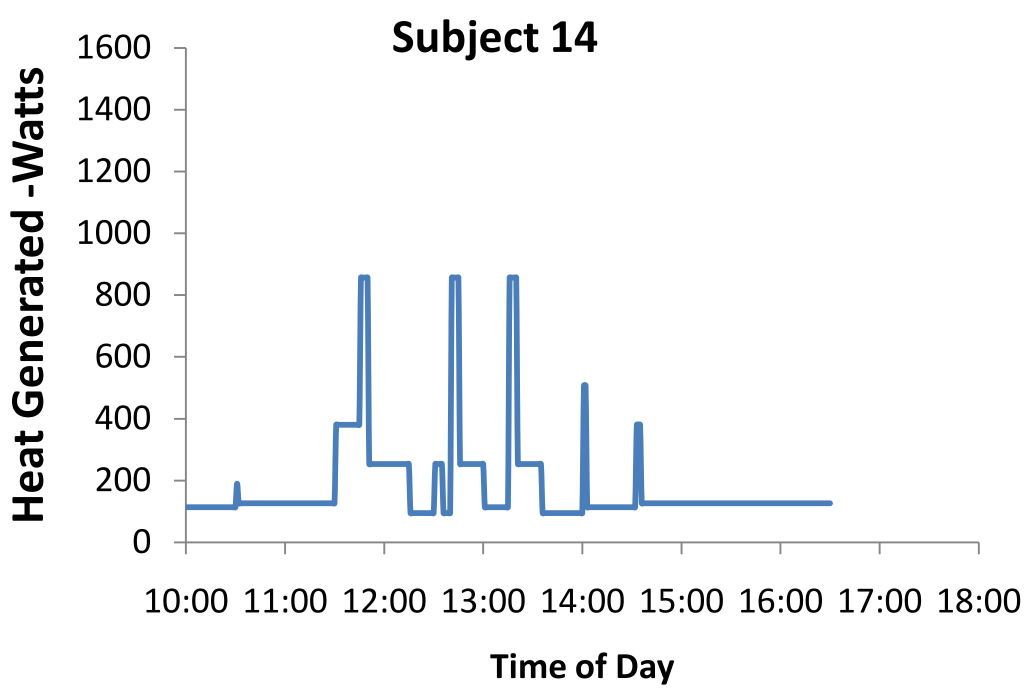
Time of Day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